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A LOWTRAN7 SENSITIVITY STUDY
in the
8-12 AND 3-5 MICRON BANDS

INCLUDES COMPARISONS WITH
LOWTRAN6 RESULTS

by

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FEBRUARY 1990

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USAF
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13. Abstract: More than 750 runs of LOWTRAN7 were made to determine how variations in certain weather variables (absolute humidity, relative humidity, wind speed, meteorological range, and precipitation) affect computed atmospheric transmittance in the 8-12 and 3-5 micron bands. This was done by changing the value of each of these weather variables, in turn, and observing the resulting change in transmittance calculations. About 30 LOWTRAN6 runs were made for comparison with the LOWTRAN7 output. Results for the 8-12 micron band showed that absolute humidity and precipitation produce the greatest decreases in transmittance. When the desert aerosol is used in LOWTRAN7, high wind speeds can produce low transmittances due to heavy dust loading. Meteorological range only becomes a strong factor in lowering transmittances when it drops below 2 km. Relative humidity is important when using the maritime aerosol, especially when it exceeds 70%.

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PREFACE

This report was prepared as part of USAFETAC Project 70909 to satisfy an AWS/XTXA request for electrooptical climatology. The report is also being used in USAFETAC Projects 80122 and 80843 to produce electrooptical climatologies for 1WW and 5WW.

USAFETAC/DNE produces climatological data by using conventional weather observations to set inputs for atmospheric transmittance model LOWTRAN7. To interpret this data correctly, analysts must know how certain atmospheric variables affect computed transmittances. To find out, we executed more than 750 runs of the LOWTRAN7 model. About 30 runs of LOWTRAN6 were then made to provide a comparison of results from past studies (using LOWTRAN6) with studies using LOWTRAN7. This report summarizes our findings.

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INTRODUCTION

USAFETAC's Electromagnetic Propagation Section (DNE) has used the LOWTRAN6 atmospheric computer model (Kneizys et al, 1983) to calculate climatological transmittance data for some time (Condray and Edson, 1989; Condray and Edson, 1988; and Edson et al., 1987). But when LOWTRAN6 was replaced by LOWTRAN7 (Kneizys et al, 1988) recently, we needed to know how results from the newer program differed from LOWTRAN6, and which weather variables cause those differences. Because most of our work has been in the 8-12 and 3-5 micron bands of the IR spectrum, we continued to concentrate on these wavelengths.

This study provides new users of GL's LOWTRAN7 computer code (as well as LOWTRAN6 users who plan to convert to LOWTRAN7) with a brief explanation of how changes in certain atmospheric variables affect model transmittance calculations for the 8-12 and 3-5 micron bands. In each set of data, all variables except one (such as meteorological range, absolute humidity, or relative humidity) were held constant to illustrate LOWTRAN7's sensitivity to each variable. Different aerosol models included in LOWTRAN7 were also compared by repeating the examination with the same series of data but with a different aerosol type (rural, maritime, urban, or desert).

The report has several limitations; for example, only two wavelength intervals (8-12 and 3-5 microns) are treated, with most of the emphasis on 8-12 microns. And within the two bands, only a few representative conditions are tested. The results are compared only to other model-generated transmittances; there was no effort to verify LOWTRAN7 against transmittances measured *in situ*.

To our knowledge, there have been no previous validation studies for LOWTRAN7 transmittance calculations. Many such efforts, however, have been performed on earlier versions of LOWTRAN. For example, Cutten (1985) compared LOWTRAN6 computations with measurements in a high absolute humidity environment and found LOWTRAN6 results to be generally accurate up to absolute humidities of 12 gm^{-3}. Cutten found that as water vapor density exceeded that figure, LOWTRAN6 began seriously underestimating transmittance in the 8-12 micron band due to poor simulation of water vapor continuum absorption. One of the primary objectives of LOWTRAN7 was to correct this problem.

Earlier versions of LOWTRAN have been verified in studies for less humid (below 12 gm^{-3}) environments; for example, LOWTRAN5 by Stillwell et al. (1980) and LOWTRAN4 by the Israeli Institute of Technology (Oppenheim and Lipson, 1984, and by Ben-Shalom et al., 1980). These studies showed that model-computed transmittances were slightly lower than measured transmittances. The longer the path length of the measurement, the larger the error.

More than 750 runs of LOWTRAN7 and LOWTRAN6 were made for this study. For ease of comparison, all runs assumed a horizontal path of 4 km at an altitude of 0.1 km AGL. The range was set to 4 km to make the results comparable with transmittances computed by the USAF IR Tactical Decision Aid (IR/TDA) as well as with previous EO climatology studies produced by USAFETAC. The low-level geometry was chosen to allow comparison with surface data. Table 1 gives geometry and frequency specifications for those runs.

TABLE 1. Standard Geometry and Frequency Specifications.

Wavelength: 8.0 - 12.0 Microns	
Wave number interval	833-1,250 at an interval of 20 cm^{-1}
Height of Sensor	100 meters AGL
Height of Target	100 meters AGL
Range	4 km
Wavelength: 3.0 - 5.0 Microns	
Wave number interval	2,000-3,333 at an interval of 60 cm^{-1}
Height of Sensor	100 meters AGL
Height of Target	100 meters AGL
Range	4 km

EXPLANATION OF RESULTS

TRANSMITTANCE Vs ABSOLUTE HUMIDITY. The amount of water vapor in the atmosphere has a significant effect on IR transmittance. This fact is especially critical in the 8-12 micron band, where water vapor absorption is the most important factor (outside of scattering due to obscurations such as fog, rain, or snow) in determining atmospheric transmittance. Table 2 provides the initial conditions used to produce Figures 1-3, which clearly show the differences between LOWTRAN6- and LOWTRAN7-calculated transmittances in the 8-12 and 3-5 micron bands. The rural aerosol model was used for these comparisons to minimize the effects of changing relative humidity on transmittance. Absolute humidity is shown vertically, while the resulting transmittances are shown along the horizontal axis.

LOWTRAN6 Vs LOWTRAN7, 8-12 Micron Band. Figure 1 shows how the modified water vapor continuum absorption of LOWTRAN7 changes computed transmittances. In drier environments (below 10 gm^{-3}), there is little difference between LOWTRAN6 and LOWTRAN7. However, as absolute humidity exceeds 10 gm^{-3}, LOWTRAN7 results can be as much as .04 higher than LOWTRAN6, an increase of more than 30% when absolute humidities exceed 20 gm^{-3}. Based on the LOWTRAN6 validation studies by Cutten (1985), in which LOWTRAN6 underforecast measured transmittances, the LOWTRAN7 results are probably more accurate.

TABLE 2. Initial Conditions Used to Produce Figures 1-3.

VARIABLE	RANGE
Pressure	1,000 mb
Temperature	300 K
Absolute Humidity	2-26 gm^{-3}
Meteorological Range	10 km
Wind Speed	0 ms^{-1}
Rain Rate	0 $mmhr^{-1}$

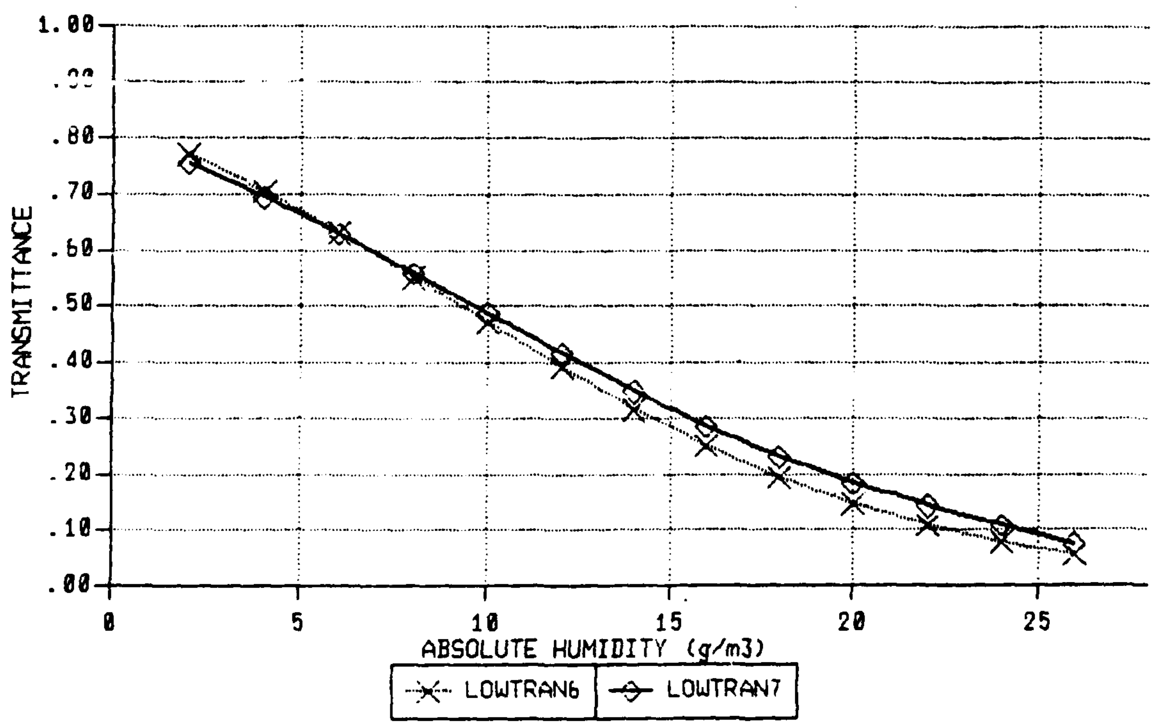

Figure 1. LOWTRAN6 and LOWTRAN7 Transmittance Vs Absolute Humidity, Rural Aerosol, 8-12 Micron Band.

LOWTRAN6 Vs LOWTRAN7, 3-5 Micron Band. As shown in Figure 2, there is less difference between model outputs in the 3-5 micron band. Although LOWTRAN7 predicts somewhat higher results than LOWTRAN6 in *drier* environments, the difference between the two is less than 10%. The two lines converge as humidity increases; above 20 gm^{-3}, there is almost no difference between LOWTRAN7 and LOWTRAN6.

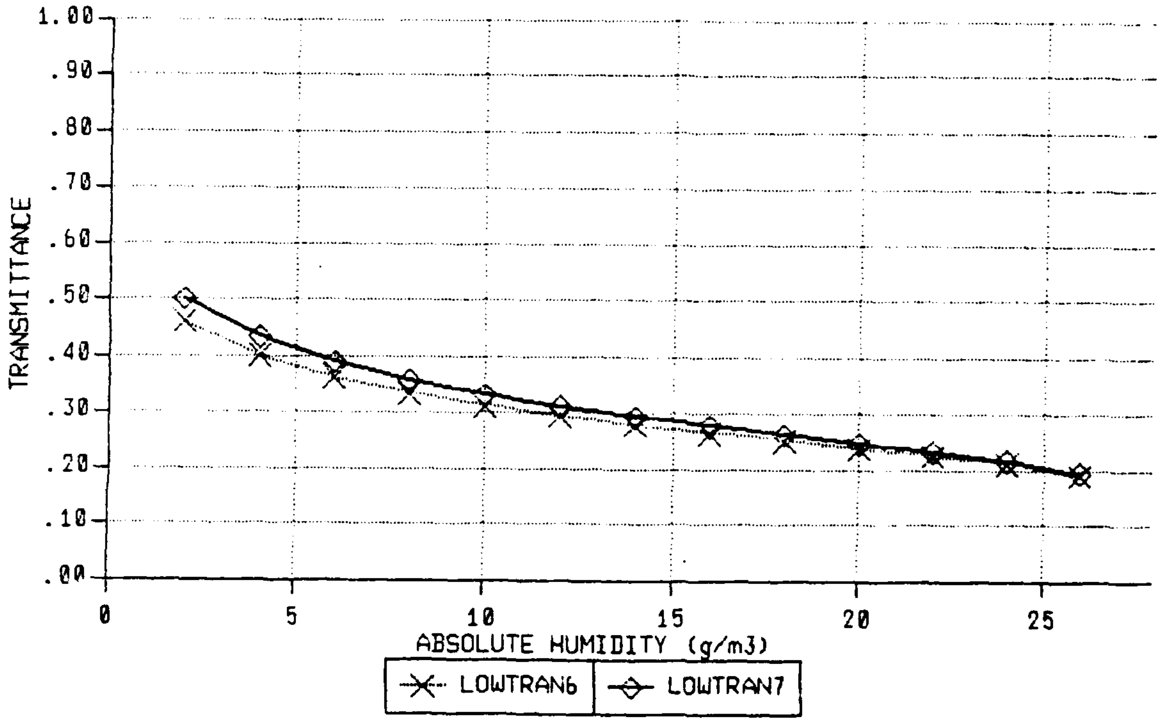

Figure 2. LOWTRAN6 and LOWTRAN7 Transmittance Vs Absolute Humidity, Rural Aerosol, 3-5 Micron Band.

LOWTRAN6 *and* LOWTRAN7, 8-12 Vs 3-5 Micron Bands. LOWTRAN7's increase in computed 8-12 micron transmittance through the rural aerosol slightly adjusts the calculated "crossover" point between 3-5 and 8-12 micron transmittances. Using LOWTRAN6 (Figure 3a) at the conditions shown in Table 2, the crossover point is just above 15 gm^{-3}; LOWTRAN7 (Figure 3b) shifted the crossover to near 16 gm^{-3}. Both models agree on the qualitative improvement of 3-5 micron transmittances compared to 8-12 micron transmittances as absolute humidity increases.

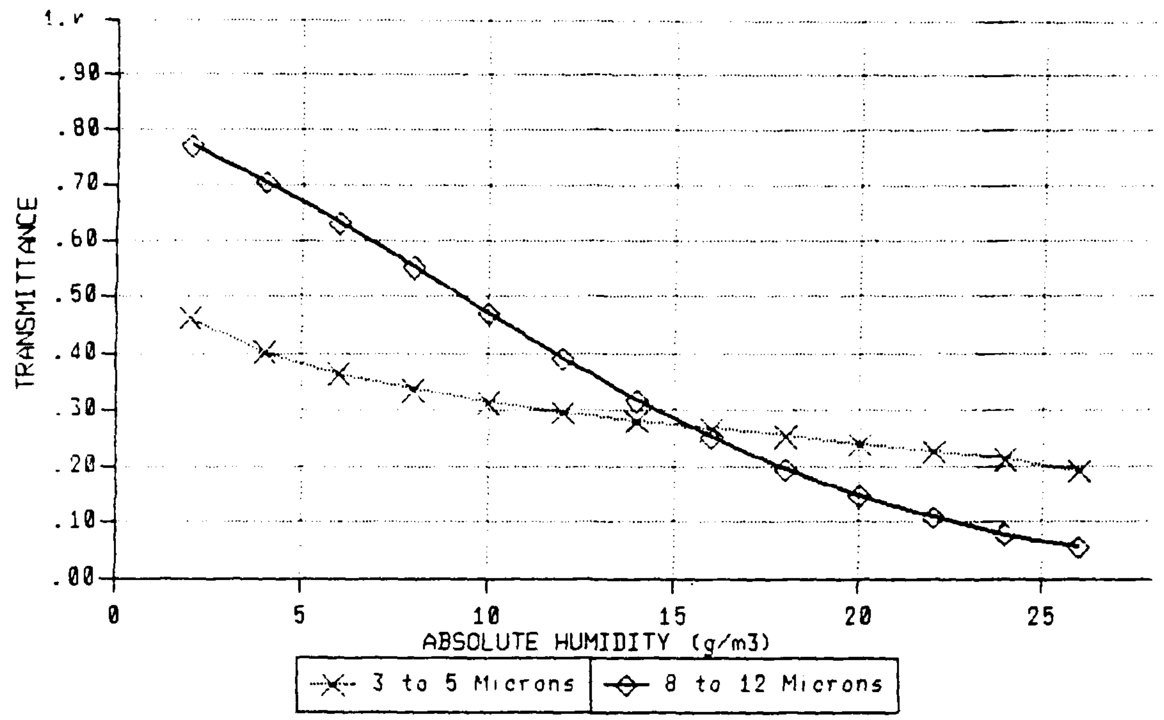

Figure 3a. LOWTRAN6 Transmittance Vs Absolute Humidity, 8-12 and 3-5 Micron Bands, Rural Aerosol.

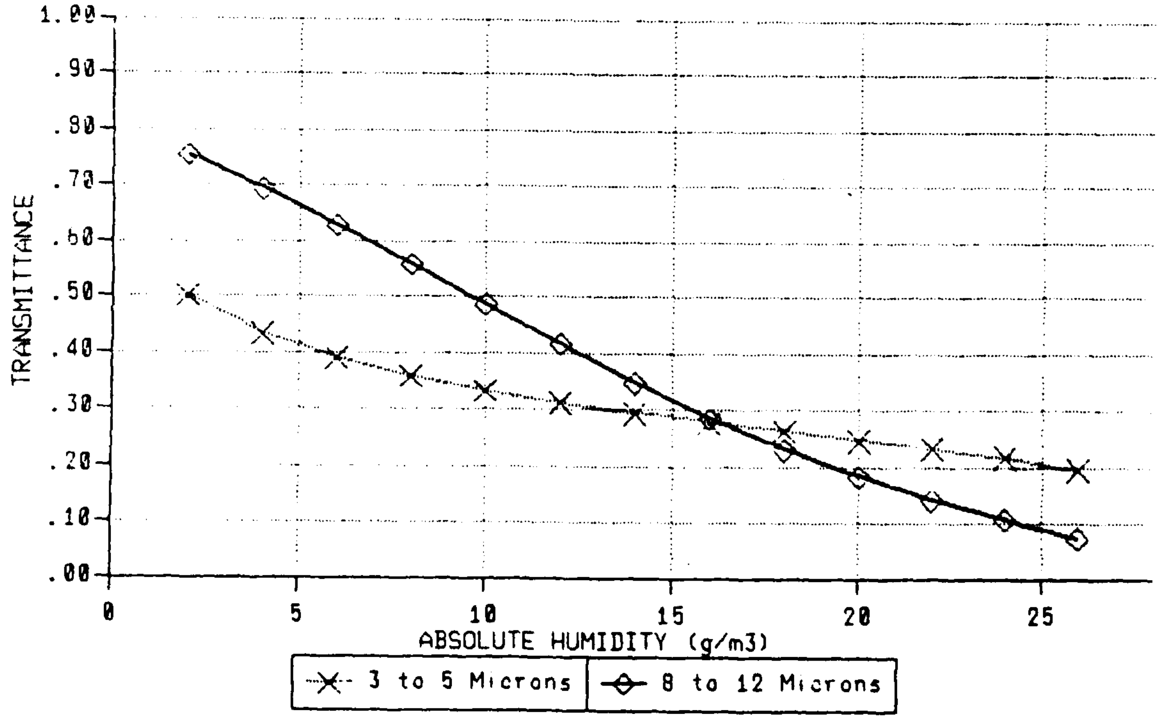

Figure 3b. LOWTRAN7 Transmittance Vs Absolute Humidity, 8-12 and 3-5 Micron Bands, Rural Aerosol.

TRANSMITTANCE Vs WIND SPEED. Two of the aerosol models in LOWTRAN7 are partially dependent on wind speed to compute the aerosol profile; these are the Navy maritime model (which is also included in LOWTRAN6) and the desert aerosol model. USAFETAC uses the latter to simulate the blowing dust conditions common over deserts and for any observation reporting blowing dust or sand as an obstruction to vision. USAFETAC does not use the Navy Maritime model, which requires an input (1-10) to describe the mixture between continental and maritime aerosols in the air mass; this is extremely difficult to determine climatologically.

Figures 4a and 4b show transmittance vs wind speed under desert conditions; Figure 4a shows a "low humidity" desert (absolute humidity = 4 gm^{-3}), and Figure 4b shows dust effects in a "high humidity" desert (absolute humidity = 20 gm^{-3}). Before the desert aerosol model was available, USAFETAC used the rural aerosol to represent desert conditions; for this reason, rural aerosol results for LOWTRAN6 and LOWTRAN7 are provided for comparison. They are both horizontal lines because the rural aerosol is not dependent on wind speed. The initial conditions listed in Table 3 were used to produce Figures 4a and 4b.

TABLE 3. Initial Conditions Used to Produce Figures 4a and 4b.

VARIABLE	*RANGE*
Pressure	1,000 mb
Temperature	300 K
Absolute Humidity	4 gm^{-3} (low humidity)
	20 gm^{-3} (high humidity)
Meteorological Range	10 km
Wind Speed	0-30 ms^{-1}
Rain Rate	0 mmhr^{-1}

Low Humidity Desert. The variation of computed 8-12 micron transmittance in a low humidity desert aerosol with changing wind speeds is shown in Figure 4a. Even under calm conditions, the desert aerosol produces slightly lower transmittances than the rural aerosol for both LOWTRAN6 and LOWTRAN7. The strongest drop in transmittance occurs when the winds are between 5 m/s and 20 m/s (transmittance with a 15 m/s wind is less than 50% of transmittance under calm conditions). After the winds exceed 20 m/s, the drop in transmittance becomes slower.

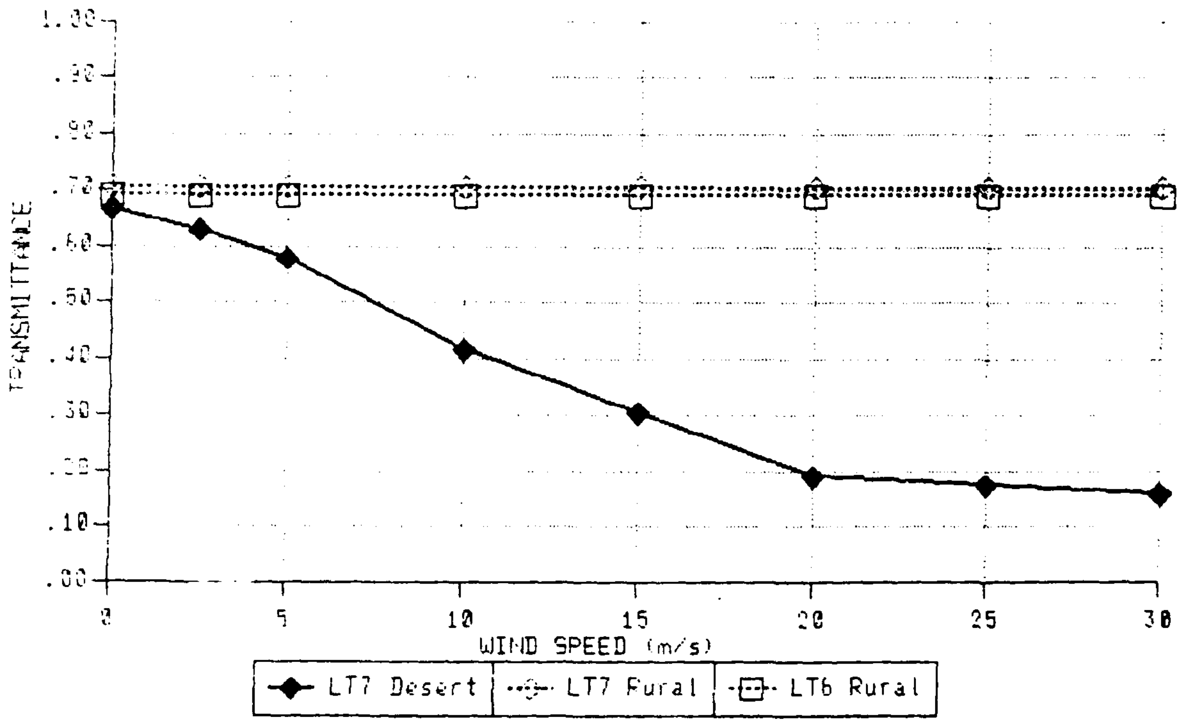

Figure 4a. Transmittance Vs Wind Speed, 8-12 Micron Band, Desert Aerosol, for Low Humidity Deserts.

High Humidity Desert. In a high humidity desert aerosol (Figure 4b), water vapor continuum absorption causes much lower transmittances than those in the low humidity case. However, the relative effect of increasing wind speeds with the desert aerosol is almost the same as before: when the wind reaches 15 m/s, the transmittance declines about 50% from calm conditions. The sharpest decline in transmittance occurs between 5 and 20 m/s.

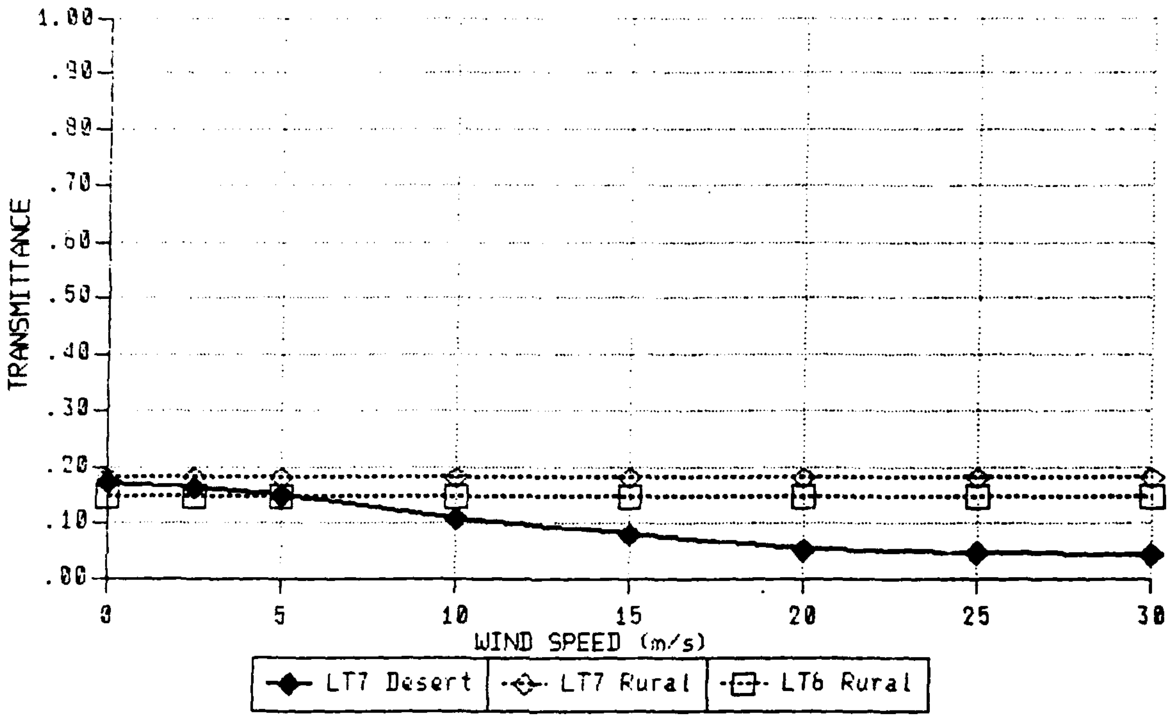

Figure 4b. Transmittance Vs Wind Speed, 8-12 Micron Band, Desert Aerosol, for High Humidity Deserts.

TRANSMITTANCE Vs RELATIVE HUMIDITY. An increase in relative humidity allows water vapor to begin condensing on atmospheric aerosols. This changes the way aerosols interact with infrared radiation by changing their size and composition. The higher the saturation level, the greater this effect will be. Because salt particles (characteristic of maritime conditions) are better condensation nuclei than most particles modeled in the other aerosol types, the Maritime aerosol is more sensitive to changes in relative humidity than the other aerosol types used in LOWTRAN7. Since absolute humidity has a much stronger effect on IR transmittance than relative humidity, the absolute humidity was held constant, while the temperature was changed to adjust the relative humidity. Each line shows the computed transmittances for a fixed absolute humidity as the relative humidity changes. Initial conditions used to produce Figures 5a-b and 6a-b are given in Table 4.

TABLE 4. Initial Conditions Used to Produce Figures 5a-b and 6a-b.

VARIABLE	*RANGE*
Pressure	1,000 mb
Temperature	273-330 K
Absolute Humidity	5-20 gm^{-3}
Meteorological Range	10 km
Wind Speed	5 ms^{-1}
Rain Rate	0 $mmhr^{-1}$

8-12 Micron Transmittance Vs Relative Humidity. Most aerosols (including urban, rural, and desert) show little or no variation in 8-12 micron transmittance as the relative humidity changes (Figure 5a), but there is a weak drop in transmittance when the relative humidity exceeds 95%. In contrast, maritime aerosol transmittances (Figure 5b) show considerably more effect as the relative humidity exceeds 70%. This decline steepens above 90%: when relative humidity reaches saturation (100%), transmittance is about 42% lower than in drier (20%) conditions.

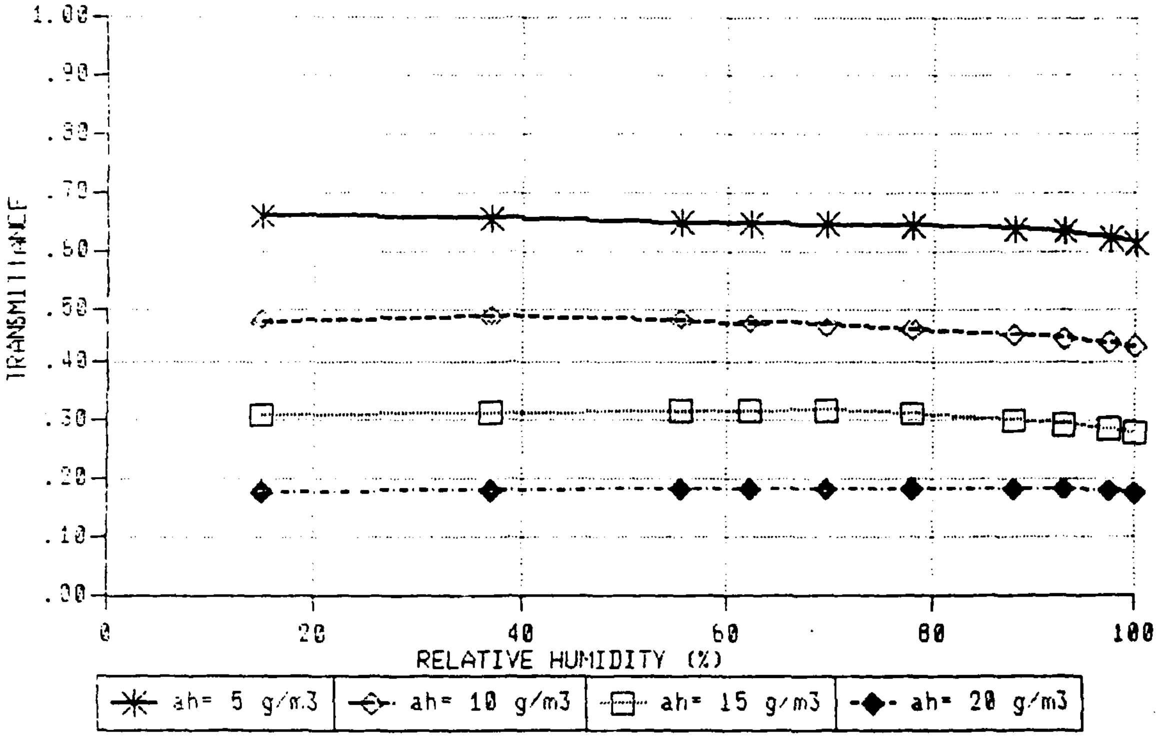

Figure 5a. Transmittance Vs Relative Humidity, 8-12 Micron Band, for Rural Aerosol.

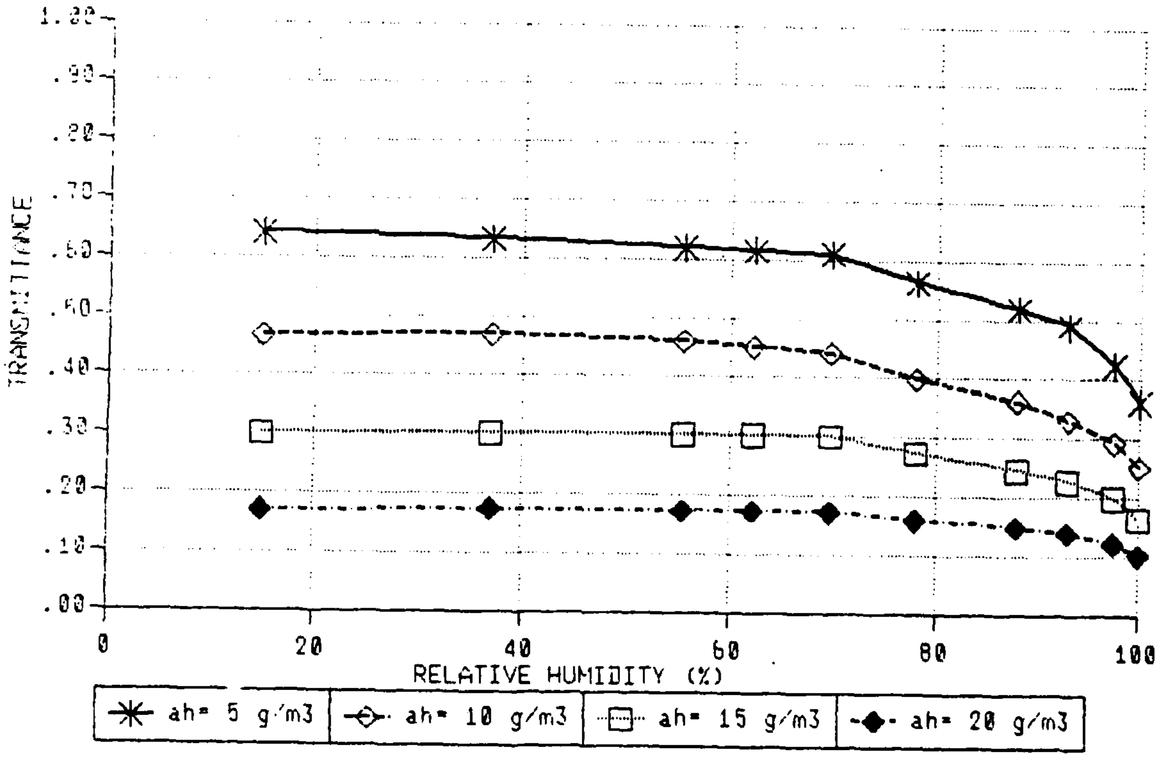

Figure 5b. Transmittance Vs Relative Humidity, 8-12 Micron Band, for Maritime Aerosol.

3-5 Micron Transmittance Vs Relative Humidity. The 3-5 micron band is slightly more sensitive to changes in relative humidity than the 8-12 micron band. For the rural aerosol (Figure 6a), relative humidities greater than 70% begin to reduce computed transmittance; however, even a 100% relative humidity reduces transmittance only about 10%. When a maritime aerosol is selected (Figure 6b), transmittances slowly decline after relative humidity exceeds 40%. The decline becomes sharper above 70% relative humidity. At 100% relative humidity, transmittance is about 60% lower than the transmittance calculated for 20% relative humidity.

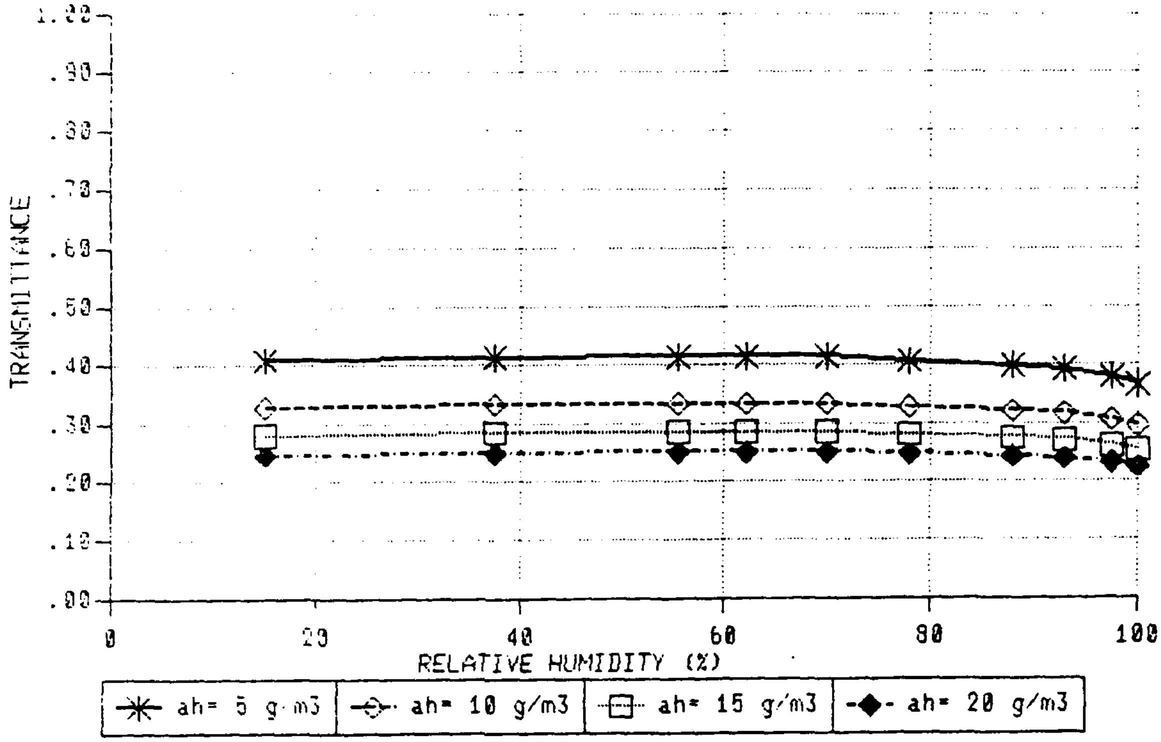

Figure 6a. Transmittance Vs Relative Humidity, 3-5 Micron Band, for Rural Aerosol.

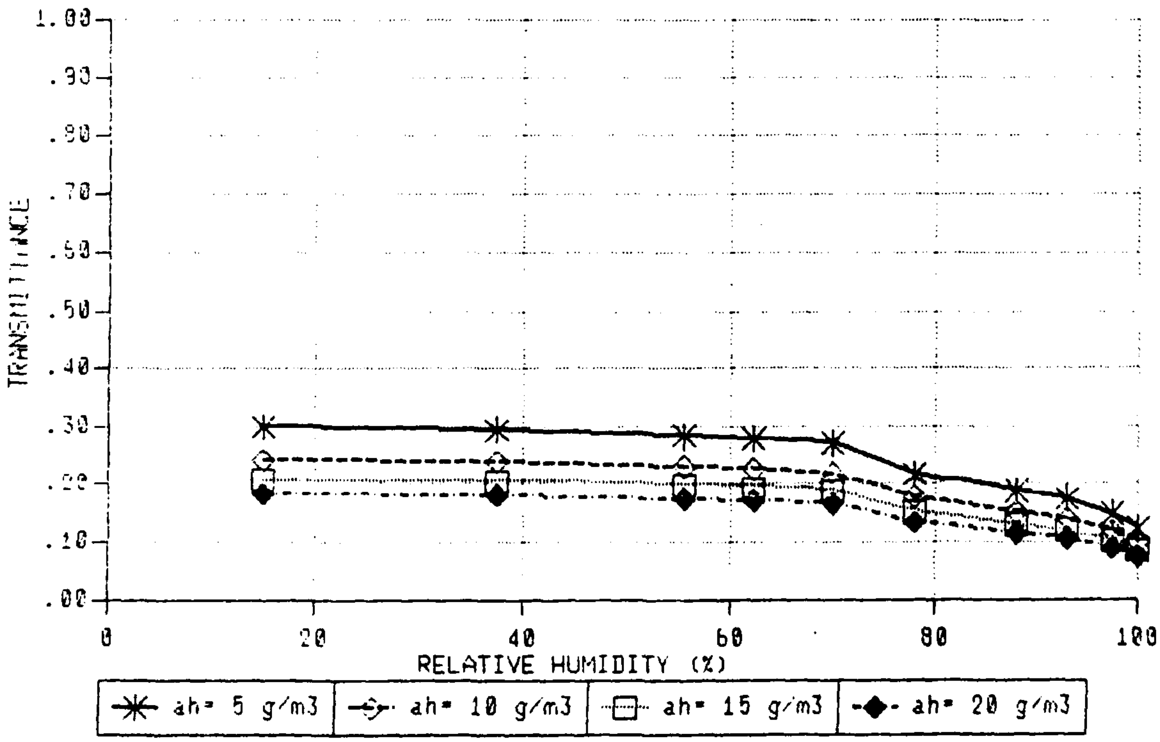

Figure 6b. Transmittance Vs Relative Humidity, 3-5 Micron Band, for Maritime Aerosol.

TRANSMITTANCE Vs METEOROLOGICAL RANGE. "Meteorological range" (V') is defined by Huschke (1959) as:

$$V' = (1/\sigma)\ ln(1/\varepsilon)$$

where σ is the extinction coefficient and ε is the threshold contrast (set equal to 0.02). LOWTRAN7 uses the input meteorological range to determine the extinction coefficient for visible wavelengths (evaluated at 0.55 μm). The extinction coefficients for other wavelengths are computed in relation to the visible wavelength extinction coefficient; because of this, the input meteorological range will influence calculated transmittances in the IR. As meteorological range decreases, aerosol extinction increases and calculated transmittance decreases. If only an observed visibility (V) is available, the meteorological range can be estimated (Kneizys et al., 1980) as:

$$V' = V * (1.3 +/- 0.3)$$

Initial conditions used to compute the transmittances in Figures 7 & 8 are listed in Table 5. Four different aerosols are provided for comparison: rural, urban, desert (wind = 5 m/s), and desert (wind = 15 m/s).

TABLE 5. Initial Conditions Used to Produce Figures 7 & 8.

VARIABLE	*RANGE*
Pressure	1,000 mb
Temperature	293 K
Absolute Humidity	10 gm^{-3}
Meteorological Range	0-10 km
Wind Speed	5 or 15 ms^{-1}
Rain Rate	0 $mmhr^{-1}$

8-12 Micron Transmittance Vs Meteorological Range. As expected, very low meteorological ranges result in poor 8 to 12 micron transmittances (Figure 7). Transmittances remain near zero when the meteorological range is less than 0.5 km. LOWTRAN7 is most sensitive to changes in visibility between 0.5 and 2 km; transmittances continue to rise with increasing visibilities above 2 km, but the change is not as great. Transmittances through the rural and urban aerosols were almost identical, while results from desert aerosols were considerably lower.

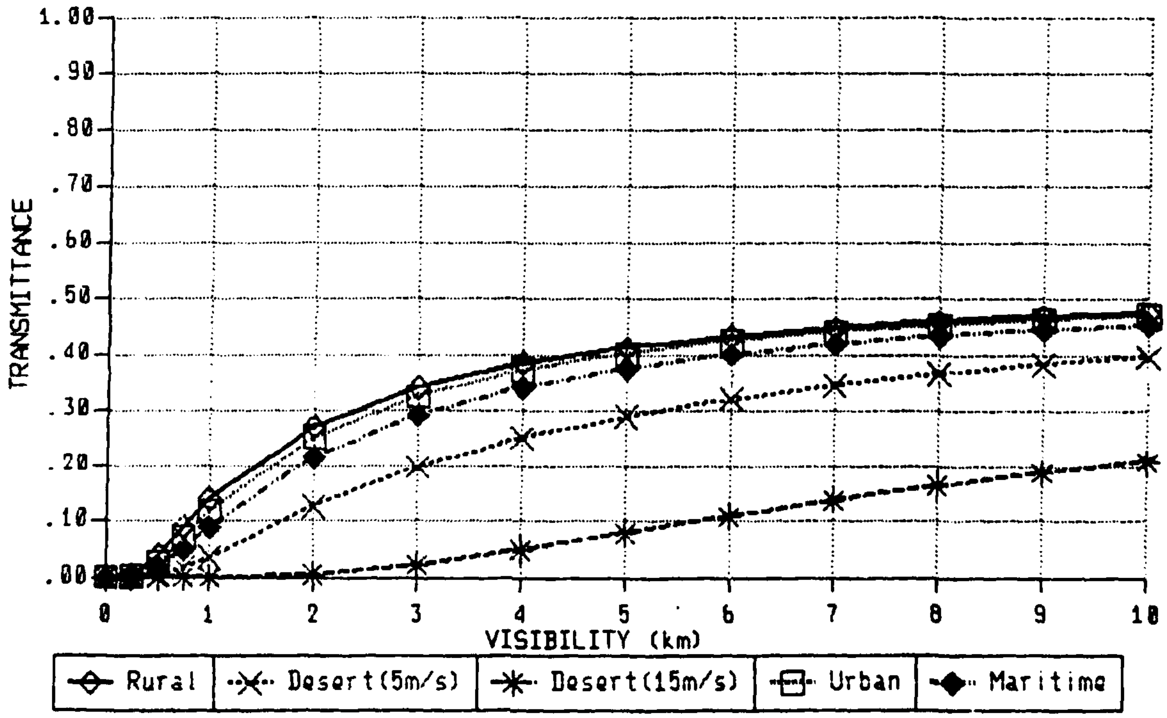

Figure 7. Transmittance Vs Meteorological Range, 8-12 Micron Band.

3-5 Micron Transmittance Vs Meteorological Range. The 3-5 micron transmittances (Figure 8) are similarly dependent on visibility. As expected, the 3-5 micron results are slightly lower than for 8-12 microns. There is a larger difference between urban and rural aerosol models in the 3-5 micron band; also, the maritime aerosol results are significantly lower in the 3-5 micron band.

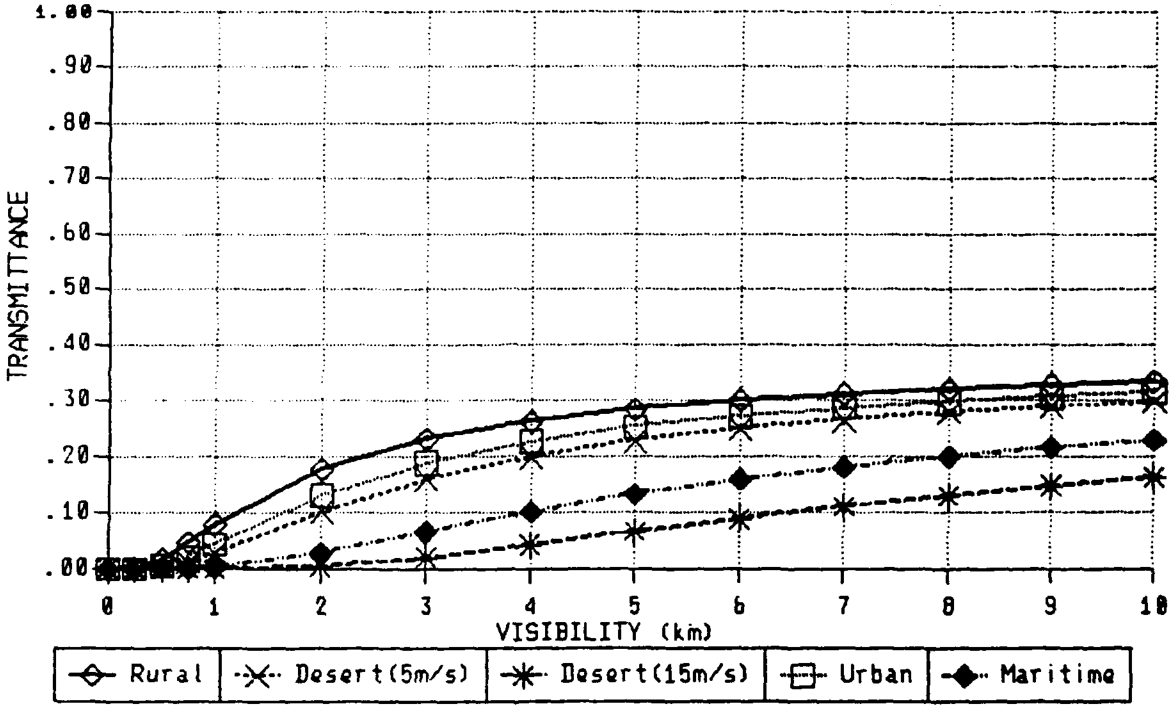

Figure 8. Transmittance Vs Meteorological Range, 3-5 Micron Band.

TRANSMITTANCES WITH PRECIPITATION. Precipitation (rain or snow) has a significant effect on infrared transmittance. The airborne water droplets (or crystals) scatter and absorb infrared radiation; as the precipitation rate gets heavier (with more and/or larger drops), the effects on transmittance increase. Note that LOWTRAN7 has no snow model; the only precipitation variable is the liquid water rain rate (in mm/hr). To analyze how precipitation degrades transmittance, Figure 9 was produced using the initial conditions in Table 6.

TABLE 6. Initial Conditions Used to Produce Figure 9.

VARIABLE	*RANGE*
Pressure	1,000 mb
Temperature	293 K
Absolute Humidity	10 gm^{-3}
Meteorological Range	5 km
Wind Speed	5 ms^{-1}
Rain Rate	0-5 $mmhr^{-1}$

In Figure 9, the abscissa shows rain rate from 0 to 5 mm/hr, while the ordinate provides the 8-12 micron transmittances. Above 5 mm/hr, transmittances are almost always near zero over a 4-km path length. The results are almost identical for all three aerosol types (rural, maritime, and desert with winds=5 m/s) tested. Even a very light drizzle (0.1 mm/hr) reduced transmittances about 28%. A rain rate of 0.25 mm/hr reduces transmittances by 46%, and a 2.5 mm/hr rain rate (still considered "light" rain by Huschke's Glossary of Meteorology--1959) dropped transmittances by almost 93%. Moderate or heavy precipitation essentially negates IR systems by reducing transmittances to zero.

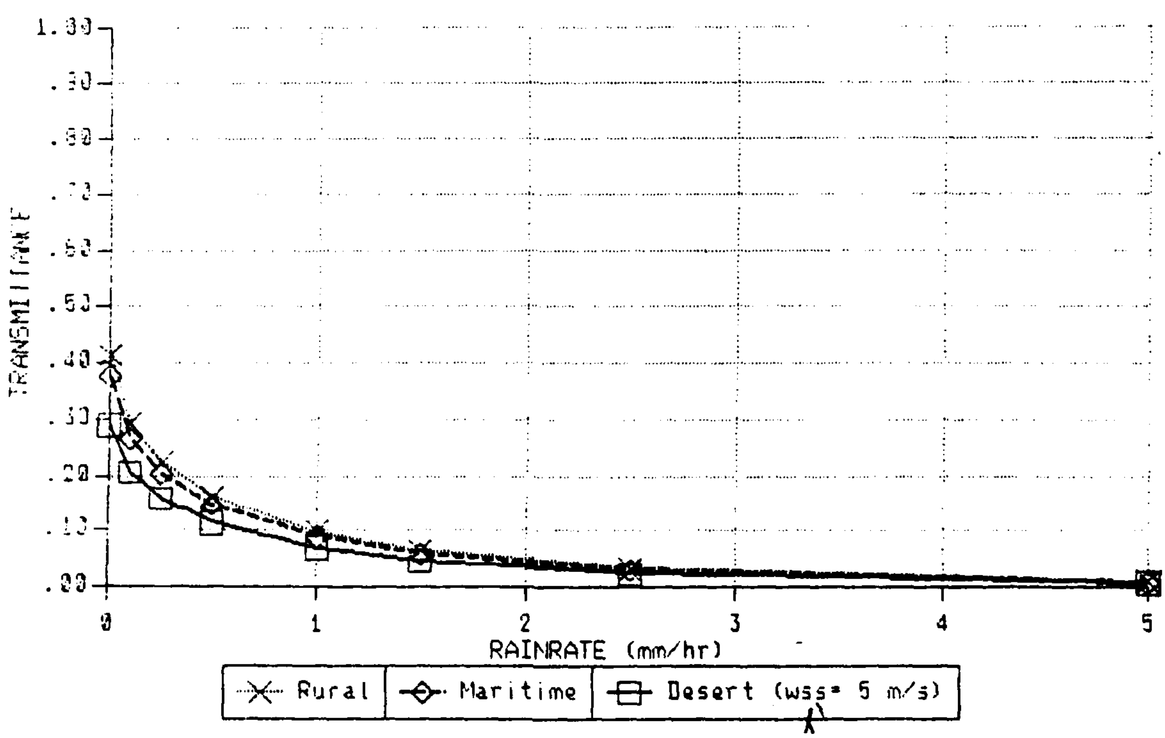

Figure 9. Transmittance Vs Rain Rate, 8-12 Micron Band.

CONCLUSIONS

More than 750 runs of the LOWTRAN7 atmospheric transmittance model were made to test how sensitive the LOWTRAN7-calculated transmittances in certain IR bands *(8-12 and 3-5 micron)* are to changes in key weather variables. This was done by holding all other inputs constant while varying absolute humidity, relative humidity, wind speed, meteorological range, rain rate, and aerosol type, in turn. In addition, some LOWTRAN6 vs LOWTRAN7 comparisons were made.

Several atmospheric variables changed IR transmittance significantly. Under most conditions, the water vapor content of the atmosphere (given by absolute humidity) was the most significant factor in determining 8-12 micron conditions. Meteorological range became important when it fell below 2 km; ranges below 1 km also reduced calculated transmittances to near zero. The new desert aerosol model produced significantly lower transmittances than the rural aerosol model; as wind speed increased, the transmittance dropped more than 50% when the wind exceeded 15 m/s. Relative humidity only became significant when the maritime aerosol was used in near saturated (greater than 70% relative humidity) conditions. With precipitation greater than 2.5 mm/hr, 4-km 8-12 micron transmittances were essentially zero.

Given a rural aerosol and an absolute humidity exceeding 20 gm^{-3}, the modified treatment of the water vapor continuum found in LOWTRAN7 resulted in 8-12 micron band transmittances up to 30% higher than those produced by LOWTRAN6.

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7WS/DON, APO New York 09403-5000	1
28WS/DON, APO New York 09127-5000	1
31WS/DON, APO New York 09136-5000	1
3WW/DN, Offutt AFB, NE 68113-5000	3
9WS/DON, March AFB, CA 92518-5000	1
11WS/DON, Elmendorf AFB, AK 99506-5000	1
24WS/DON, Randolph AFB, TX 78150-5000	1
26WS/DON, Barksdale AFB, LA 71110-5002	1
4WW/DN, Peterson AFB, CO 80914-5000	3
2WS/DON, Andrews AFB, MD 20334-5000	19
5WW/DN, Langley AFB, VA 23665-5000	3
5WW/DO, Langley AFB, VA 23665-5000	1
1WS/DON MacDill AFB, FL 33608-5000	1
3WS/DON, Shaw AFB, SC 29152-5000	1
5WS/DON, Ft McPherson, GA 30330-5000	1
25WS/DON, Bergstrom AFB, TX 78743-5000	1
AFGWC/SDSL, Offutt AFB, NE 68113-5000	3
AFGWC/DO, Offutt AFB, NE 68113-5000	1
AFGWC/WF, Offutt AFB, NE 68113-5000	1
USAFETAC, Scott AFB, IL 62225-5438	6
7WW/DN, Scott AFB, IL 62225-5008	3
6WS/DON Hurlburt Field, FL 32544-5000	1
15WS/DON, McGuire AFB, NJ 08641-5002	1
17WS/DON, Travis AFB, CA 94535-5986	1
3350 TECH TG/TTGU-W, Stop 62, Chanute AFB, IL 61868-5000	2
AFIT/CIR, Wright-Patterson AFB, OH 45433-6583	1

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NAVOCEANCOMFAC, Stennis Space Ctr, MS 39529-5002 1
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NAVOCEANO, Code 4601 (Ms Loomis), Stennis Space Ctr, MS 39529-5001 1
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NOARL, Monterey, CA 93943-5006 1
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Naval Postgraduate School, Chmn, Dept of Meteorology, Code 63, Monterey, CA 93943-5000 1
Pacific Missile Test Center, Code 4230, Pt Mugu, CA 93042-5000 1
Naval Weapons Center, China Lake, CA 93555-5000 1
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GL/OPE, Hanscom AFB, MA 01731-5000 5
GL/LYA (Attn: Maj Hancock), Hanscom AFB, MA 01731-5000 1
Atmospheric Sciences Laboratory, Attn: SLCAS-AT-AB, Aberdeen Proving Grounds, MD 21005-5001 1
Atmospheric Sciences Laboratory, White Sands Missile Range, NM 88002-5501 1
U.S. Army Missile Command, ATTN: AMSMI-RD-TE-T, Redstone Arsenal, AL 35898-5250 1
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DTIC-FDAC, Cameron Station, Alexandria, VA 22304-6145 2
AUL/LSE, Maxwell AFB, AL 36112-5564 1
AWSTL, Scott AFB, IL 62225-5438 50